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A SYSTEM FOR TORQUE CHART ANALYSIS

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A SYSTEM FOR TORQUE CHART ANALYSIS

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ABSTRACT:

The system for torque chart analysis is based on the theoretically ideal chart, which is uniform, level, has a low magnitude, a low band-width, no torque peaks, and a low frequency of variation for the instantaneous torque. The median torque line, in gram-centimeters times 100, provides the basic demerit number and is the base from which all deviations are identified for the application of demerit points.

This system is the first of its kind. Results obtained in 291 applications make reasonable distinctions in the qualities of ball bearings, and these distinctions conform to the qualitative opinions of experts. Semi-quantitative evaluations of particular qualities of ball bearings are now possible, and this fact may make it possible to write more explicit bearing specifications.

The basic factors analyzed by this system are the magnitude, the rate of change, the frequency, and the randomness or regularity of an event. The events considered are torque, torque peaks, and band-width. An arbitrary demerit scale has been devised to apply to these factors and events.

At present, the system finds it's greatest value in making reliable and consistent comparisons between torque charts, either for the same or different bearings. However, the nature of the system is such that there is now a possibility for an absolute, instead of a relative, evaluation.

The system is simple, easy to apply, and easily adapted to special needs. The manner in which data is recorded permits a direct comparison of individual events, and the relative weight of the demerit points for that event is easily changed on the basis of experience or theory.

INTRODUCTION:

1. This report describes an interesting by-product resulting from a program which was undertaken to determine the feasibility of cleaning ball bearings with ultrasonic energy. This by-product is a method for analyzing torque charts on a semi-quantitative basis. A bearing may now be rated on a numerical basis for each of three major factors. The method is based on 291 torque charts made with 51 bearings. (Ultrasonic cleaning of individual ball bearings has been found effective and feasible. Group or continuous cleaning has not yet been investigated.)

Enclosure (1)

2. It is hoped that the proposed system of chart analysis will help attain the fundamental objective, namely, the correlation of torque chart characteristics with useful bearing life, excellence of the bearing performance, and the proper application of the bearing. An additional feature might be the development of a method for writing bearing specifications for either cleanliness or performance, or both.

TORQUE CHART ANALYSIS: GENERAL FACTORS

1. A torque chart might be analyzed on the basis of experience in ball bearing application, or on a purely mathematical basis. Although neither is likely to prove adequate by itself, the combination of the two methods is more likely to lead to the development of a sound and useful theory. For example, the first idea that might appeal either to the mathematician or the ball bearing expert is the measurement of the area under the torque curve. The units involved are gram-centimeters (work) and time. Thus, the area under the curve, which would be difficult to obtain and also tedious- or expensive, if done by automatic machines- would represent only the total work done to turn the bearing through one revolution.

2. This same information is available in less precise form by merely looking at the general torque level. However, it is also apparent that much other information is lost if only the torque level is considered. Is it important if the torque of a bearing varies? In a regular manner? In a random manner? In distinct plateaus? What is a peak on a torque chart? When does this peak assume significance? How important is the magnitude of the instantaneous torque variation (band width)? How important is the frequency of the instantaneous torque variation?

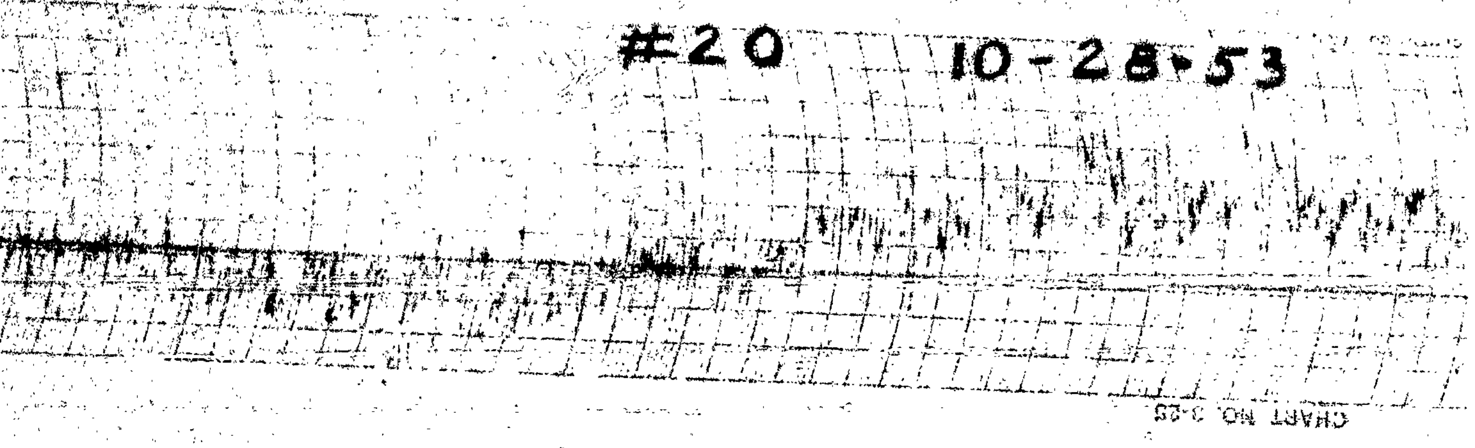
3. Four important factors are evaluated for each of three chart characteristics: (a) magnitude, (b) rate of change, (c) frequency, and (d) the randomness or regularity of an event are applied to torque level, to torque peaks, and to band width.

4. Table 1. illustrates the method which is used to analyze a torque chart. In this case, bearing #20 was analyzed on 10-28-53, as received from the original package. This bearing was new and intended for immediate use. On 11-6-53, the same bearing was analyzed again after having received an ultrasonic cleaning treatment. On 11-13-53, the same bearing was analyzed a third time, when it was cleaned by conventional methods, which cleaning followed the ultrasonic cleaning.

TORQUE CHART ANALYSIS: OBTAINING DATA

1. The analysis of the charts, shown in Plate 1, is based on a theoretical median torque value. This median value is the line which, if drawn through the torque chart, would have as much of the chart above the line as below. It may be pointed out by people with experience in ball bearing testing and with experience in the operation of torque testers that this line is not necessarily a true measure of the median torque.

PLATE 1



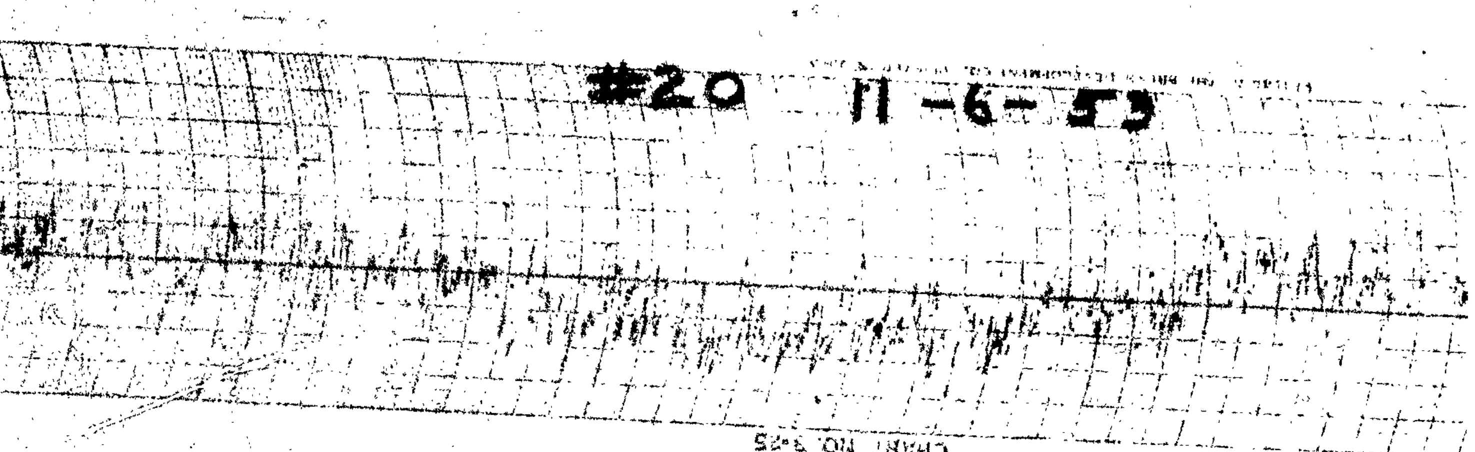
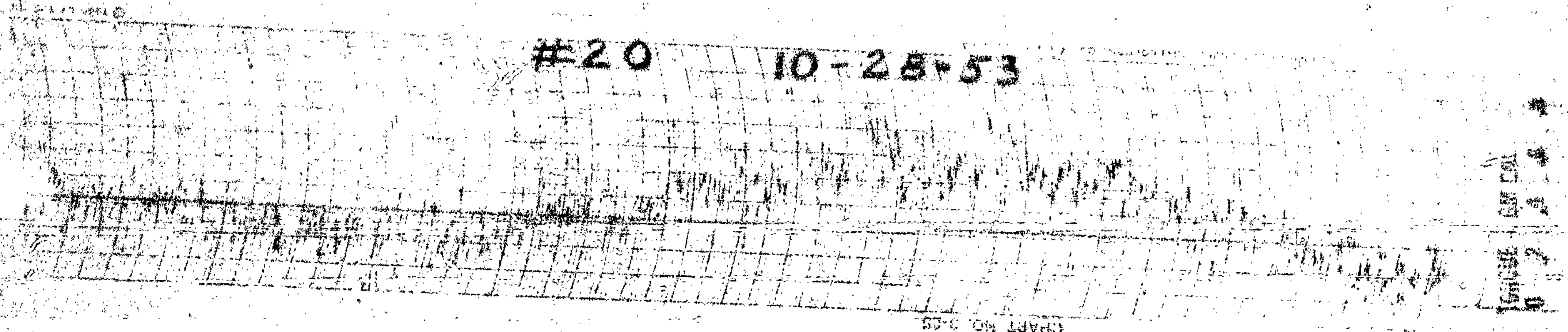


PLATE I



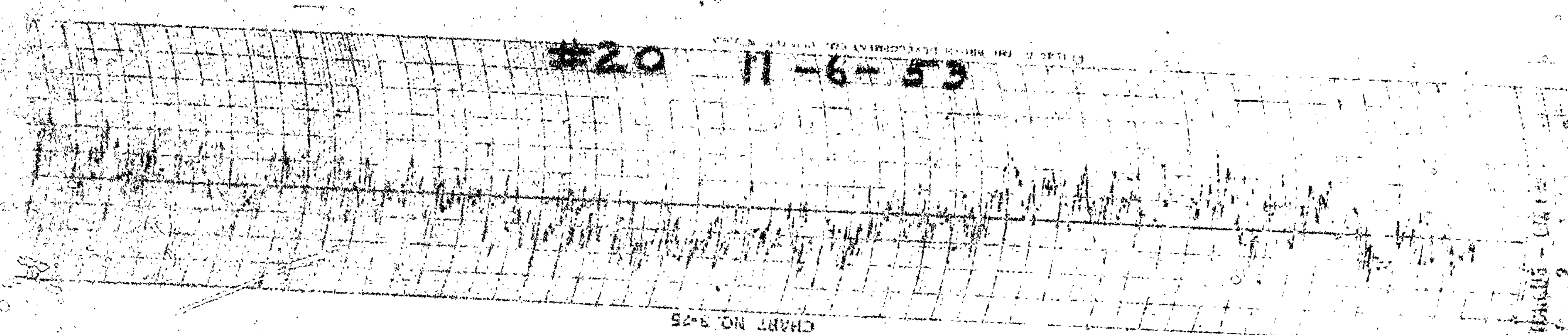


TABLE I

	TORQUE															PEAK						BAND WIDTH		
		LOW VALUES				HIGH VALUES					WEIGHTING FACTORS			HANG-UPS										
Date	M_1 = median torque value	M_2 = low torque value	n_2 = no. of low torque values	$d_2 = M_1 - M_2$	$t_2 = n_2 \times d_2$	M_3 = high torque value	n_3 = no. of high torque values	$d_3 = M_3 - M_1$	$t_3 = n_3 \times d_3$	$e_3 = t_2 + t_3$	$C = 1/10\ e_3$ for cyclic variations	$R = 1/5\ e_3$ for random variations	$P = e_3$ for torque level plateaus	n_4 = no. of chart units off-scale	$M_4 = n_4 \times 10$	E_5 = torque demerits $= M_1 + (C \text{ or } R \text{ or } P) + M_4$	n_6 = no. of on-scale peaks	n_7 = no. of off-scale peaks	$N_7 = n_7 \times 5$	$t_7 = n_6 + N_7$	n_8 = no. of test revolutions	$E_9 = t_7 \div n_8$ = peak demerits	e_{10} = band width demerits	e_{11} = noise demerits	$E_{12} = e_{10} + e_{11}$
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
10-28	22	14	2	8	16	48	1	26	26	42	-	8	-	-	-	30	6	2	10	16	1	16	24	15	39
11-6	30	16	1	14	14	48	1	10	10	24	2	-	-	-	-	32	1	-	-	1	1	1	20	10	30
11-16	35	20	3/3	15	15	50	3/3	15	15	30	5	-	-	-	-	38	-	-	-	-	1	-	20	10?	30

It may be that only the instantaneous peaks of the torque chart should be considered in estimating the average torque value. It is a fact that the instantaneous value recorded from a maximum to a minimum has no real significance, because the torque tester is coasting at that time. However, the instantaneous reading from a minimum to a maximum is a positive reading and can be used. The justifications which are used for the median line first proposed are: (a) its practicality and ease of application, (b) its 50% chance of being theoretically correct, and (c) its statistical chance for averaging out any theoretical error.

2. In the analytical procedure of Table 1., it is intended that the median torque value shall be the dominant factor over torque peaks and band width. For this reason, and for convenience in recording, the actual torque value in gram-centimeters is multiplied by 100 before recorded in column 1. This will be the basic figure to which demerit points will be applied for all types of variation from the theoretically excellent curve, which is uniform, horizontal, has a small band width, and a low frequency of instantaneous torque variation ("noise").

3. The next step in the analytical procedure is to look at the torque curve from one end of the chart, looking down the theoretical median line. (In analysis, it is much easier to actually draw this line.) A number of different variations may now be seen. In some charts, there will be only a minimum variation about the median line. In others, the variation may be so pronounced as to resemble a sine wave, and in this case, several distinctions must be noted. Cycling of the torque level is defined as any condition in which the maximum instantaneous peaks of the low portion are under the minimum instantaneous peaks of the high portion. It is clear that the band-width of the instantaneous variation affects this determination.

4. A word of caution must now be added. If some of these definitions and procedures seem inexact or not sufficienty specific, it should be remembered that this is an initial proposal, that it was originally designed for comparative purposes, and that any attempt to read information to two decimal places when the chart is accurate only to the closest whole number (a figurative comparison only) is obviously misleading. Eventually, if the ideas and procedures here proposed are widely accepted, it may prove worthwhile to make fine measurements, but solely for the purpose of correlating with useful life, excellent performance, and application of a bearing.

5. Having determined that deviations from the median torque line exist, their magnitude and number are next recorded. The magnitude is determined again by drawing (or estimating) the median line through the central portion of the tops and the bottoms of the sine wave portion of the curve. The level of such lines is recorded in gram-centimeters times 100. The number of such high and low readings is also recorded. For practical purposes, if the magnitudes of the high values are not very widely separated, a single high value is recorded. The same type of recording is used for low values.

6. Another type of variation might be seen from an end view of the torque curve. In this case, several different plateaus might be seen: consecutive uniform torque levels existing for about 1/4 revolution each at 0.15, 0.25, 0.20, and 0.35 gram-centimeter. In this case, and in cases where high (or low) variations are distinct, each separate level (times 100) is recorded. Actually there is no distinction in the recording process, only in the section where weighting is applied.

7. Frequently, a torque chart is seen in which the torque runs off-scale for more than 1/2 chart unit. This type of reading is called a hang-up. The significant feature of this part of the chart, in addition to its existence, is its duration, and this is recorded as the number of chart units which are off-scale. All readings exceeding 0.7 gram-centimeter are regarded as off-scale. The weighting factor of 10 is applied to such events, to distinguish them from off-scale peaks, which are readings exceeding 0.7 gram-centimeter for less than 1/2 chart unit. Off-scale torque peaks have a weighting factor of 5, so the distinction now made between on-scale peaks, off-scale peaks, and hangups is a weighting factor of 1 for on-scale peaks, 5 for off-scale peaks, and 10 for hang-ups.

8. These weighting factors are arbitrary. However, their application to 291 torque charts shows that they work in ranking the various charts so as to agree with experienced observers' interpretation of the same charts. Perhaps someone may find a more valid theoretical basis for weighting the individual factors. Or perhaps others may find different weighting factors more suitable for different bearing applications. Sometimes the rate of change of torque- whether general or instantaneous- is more important than the magnitude of the change or the torque level at which the changes occur.

9. The analysis of torque peaks is broken into two parts. One is concerned with on-scale peaks, the other with off-scale peaks. On-scale peaks are recorded only as the number of occurrences per bearing revolution. All peaks are counted, and then the total divided by the number of revolutions. Although the magnitude of the individual instantaneous peaks might be taken into account, and this would probably be better from a theoretical standpoint, it is felt that practicality is obtained in this manner without any great loss in analytical accuracy. Instantaneous peaks are counted only if they are easily discernible outside the nominal band-width.

10. Band width has some significance in torque chart analysis, but at the moment it is hard to define on a theoretical basis. Because differences have been noted, two possible data systems are suggested. In one system, a qualitative scale is set up. The width of the envelope which would contain practically all maxima and minima of the instantaneous torque peaks (and which envelope should be sketched on the chart to simplify analysis) is defined as the band width. In the qualitative scheme, this band width would be very poor, poor, average, good, and very good. Very good would be worth an arbitrary 5 points, each poorer classification an additional 5 points, so that very bad would have 25 demerit points. For more accurate evaluation, the distance between the envelope lines might be measured in chart or arbitrary units.

Since these charts were evaluated on a comparative basis, the qualitative scheme was used with relative success.

11. Finally, the frequency of variation of the instantaneous torque peaks is rated. Again, the same qualitative scheme can be used that was applied to band width, or, for closer evaluation, the peaks occurring in 1/10th complete revolution could actually be counted (rather easily, probably, with the aid of a magnifying glass) and multiplied by 10.

12. In several cases, data in Table 1., was recorded as a fraction. The numerator is the sum of the events, while the denominator is the number of revolutions.

TORQUE CHART ANALYSIS: USING THE DATA

1. The positive difference between the median torque value and the low value is computed and recorded in Column 4. The amount of the low deviations from the median value is multiplied by the number of such occurrences and recorded in column 5. A similar proceeding is followed for the high deviations. Columns 5. and 9. are added and recorded in Column 10. as the total deviations.

2. These deviations are then weighted according to the following scale: 1/10th the amount in Column 10. for regular variations, 1/5 the amount in Column 10. for random variations, and the total amount in Column 10. for torque charts which exhibit plateaus. Again, this weighting scale is arbitrary, but it seems to work. The weighting is recorded in only one of the Columns 11, 12, or 13.

3. The remainder of the table can be understood by observing the column headings, because operations are indicated.

EVALUATING THE SYSTEM:

1. If the proposed factors for rating are acceptable, then this system has the following merits. Single factors, such as median torque values, the number of highs or lows in a sine type variation, or the number of peaks, can be compared directly. The weighting factors can be easily changed on the basis or experience or theory. The actual analysis of the chart is quite rapid- 4 minutes per chart including handling of the chart, recording the data, calculations, and filing the chart. The analysis of the chart requires very little equipment. An individual could be trained to analyse such a chart in a short time- perhaps two hours direct time, four hours elapsed time. The system has merit by its ability to provide consistent sets of data for comparisons.

2. The idea of applying numerical demerits to individual factors of the torque chart permits, for the first time, the possibility of establishing a semi-quantitative rating system for bearings. If t'e proper weighting factors can be worked out either by experience or theory, then it may be possible to combine all factors into a single demerit number equivalent to that of a golf score, and the bearing with the lowest score would be best.

At present, it is felt that a 3-part number, one for torque, another for peaks, and a third for band width, is adequate to characterize a bearing.

3. It may be possible to use the median torque alone as the basic factor, and to add demerit points based only on the number of high and low sine waves observed, and the number of peaks of any kind.

4. There is, finally, the hope that the analysis of torque charts, prepared with top side up and top side down, may lead to an estimate or evaluation of internal dimensions and characteristics of the bearing geometry.

PITFALLS:

1. During the course of all these torque tests, in connection with the ultrasonic investigations, it was found that a surprisingly large number of variables can come into operation and thereby invalidate the resulting torque charts. The two principal problems are reproducibility and accuracy, and these are interwoven with the variability inherent in the ball bearing itself and in the torque tester.

2. A reliable torque chart should show a repetitive pattern in at least two consecutive revolutions of the bearing. If irregularities occur, then enough additional revolutions should be obtained until it is statistically probable that the irregularities are random or regular. It is the writer's preference to obtain a minimum of 3 consecutive revolutions, plus additional ones if needed.

3. Sufficient evidence was found during the ultrasonic investigations to merit careful examination of a number of other factors which are commonly taken for granted if reproducibility is to be assured. First of all, there must be a check to insure that the weight on the bearing, during the torque test, is properly seated. This type of check requires that the bearing be tested at least twice- so that the weight must be placed on the bearing in two separate operations. It has also been found that entirely different charts can be obtained by simply turning over the bearing, and retesting it, and then testing with the original side up.

4. Lubrication, the type of lubrication, and the manner in which the lubrication is applied can also influence the character of a torque curve. There may also be a distinct change in the type of torque curve obtained from a bearing which is tested and then retested after a time interval of perhaps 4 weeks, under conditions as like the original as possible.

5. With all the variabilities noted thus far, it is easy to see that a torque chart can be quite far from presenting an adequate picture of the performance or characteristics of a ball bearing. And to top this off, there must also be some consideration given to possible variations in the torque tester itself.

CONCLUSION:

1. In the writer's opinion, a complete and accurate picture of a ball bearing's torque characteristics can be obtained only if the following tests are performed:

a. Every torque test must be made with at least two consecutive revolutions for each side which is tested. Additional consecutive revolutions should be taken if irregularities are observed.

b. Each bearing should be tested, without lubrication, in the following sequence:

i. Axis vertical, Stamped side up.
ii. Axis vertical, Stamped side down.
iii. Repeat steps i and ii.

c. The sequence of tests given in step "b" should be repeated with lubrication.

2. Although these are necessary conditions to obtain a full and accurate picture, they still do not insure that the correct picture will be obtained. A great deal more of fundamental information is necessary before it can be decided how accurately a set of torque charts will describe an individual bearing.